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Assessment of Flight Crew Errors Based on THERP

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Abstract

The purpose of this study is to reduce the aviation accidents and incidents induced by flight crew errors. A flight crew errors analysis and classification system is developed preliminary. In combination with aviation flight accidents exploration, and interviews with pilots, the human error modes which will occur in the flight task are identified. A quantitative method to assess flight crew errors is established on Technique For Human Error Rate Prediction (THERP). In a case study, the takeoff task is analyzed, the human error modes and consequences are identified, and the failure probability of takeoff task is calculated. Those results are useful for SSA (System Safety Assessment) to improve the aircraft safety design.

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1. Introduction

Aviation safety depends on the aircraft design, manufacture, entry into service and maintenance throughout the whole life cycle of an aircraft. The statistic data show that about 75% of aviation accidents are induced by human factors, and that human error is the primary risk to flight safety [1,2]. The ultimate way to improve this status is to take into account the human factor issues at the very beginning of the aircraft type design.

In the old days, the safety design philosophy was merely focused on purely technological issues such as hardware performance and reliability. Along with the evolution of aeronautics and aerospace, it is widely recognized that, being a complex system, human does have significant effects on aviation safety.

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Nowadays, as a part of probabilistic risk assessment (PRA), human reliability analysis (HRA) has made important contribution to the improvement of the Nuclear Power Plant safety [3]. Technique For Human Error Rate Prediction (THERP) is the first approach in HRA and is still widely used in a range of applications even beyond its original nuclear setting.

Compared with PRA, System Safety Assessment (SSA) is a systematic and comprehensive evaluation of implemented system to show that relevant safety requirements are met [4]. SSA is a suit of effective methodologies to insure the safety level of the aircraft.

This study attempts to use THERP to assess human errors and integrate the results into SSA to supplement the current safety assessment methodology.

2. Identification of Flight Crew Errors

The first step to assess flight crew errors is the human error identification (HEI). There are many human error identification systems, and each of them has its own taxonomy and purpose. For instance, TRACER was developed with experimental studies, literature review and analysis of ATC incidents to reduce human errors in air traffic control. Likewise HFACS was established with Reason's model for the investigation of accidents. Additionally, Human Error Template (HET) has been developed specifically for the aerospace. However, the HET error taxonomy was based upon the External Error Modes (EEM) and is a qualitative method.

2.1. Flight Crew Errors Analysis and Classification

In this paper, a flight crew error analysis and classification system is developed as shown in Fig 1, which synthesizes the O'Hare classification frame of flight crew error assessment, the Wickens' information processing model, the Rasmussen's model and the Hollnagel's error classification theory. The brief description is as follows:

There are four models in this system. Combined with the exploration of aviation flight accidents/incidents and interviews with pilots, the human error modes are identified.

(1)Model 1: Information acquisition and detection based on stimulus and task

There are four aspects for pilots to acquire information: the visual sensation, the auditory, the spatial orientation and the experience & knowledge. And the human errors could be omit, lapse, timing error, spatial illusion and wrong partten.

(2)Model 2: Information Perception based on knowledge and rule

Generally, there are two ways to perceive information for the pilot: the information perception based on the rule and on the knowledge. And the human errors could be omit, lapse, timing error and wrong partten.

(3)Model 3: Information decision and response selection based on knowledge and rule

Generally, there are two classes: the decision making based on the rule and on the knowledge. And the human errors could be omit, lapse, timing error and decision-making error.

(4)Model 4: Information response execution based on skill

Hollnagel[5] defined eight types of human error actions. According to our analysis, five types of human errors in this stage are identified. The human errors could be the force error, the direction error, the timing error, the sequence error and the speed error.

According to the analysis on each model, we established the chart as shown in Table 1.

Table 1. Flight crew error modes

Number	1	2	3	4	5
Human error mode	Omit	Lapse	Spatial illusion	Wrong pattern	Decision-making error
Number	6	7	8	9	10
Human error mode	Direction error	Timing error	Speed error	Sequence error	Force error

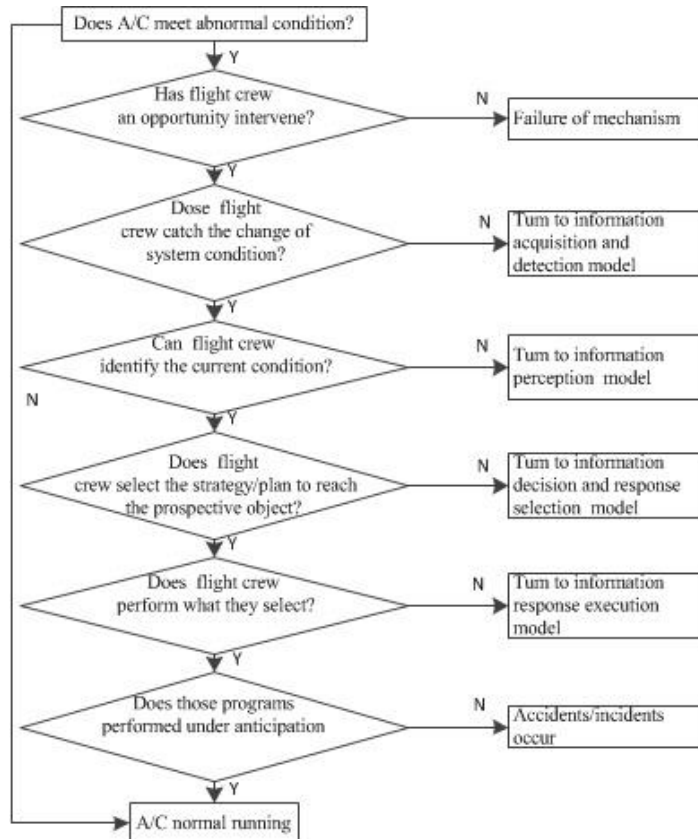


Fig. 1. Flow chart of Flight crew analysis and classification system

2.2. Performance Shape Factors(PSF)

So as to correct the human error probability, any factor that influences human performance is designated as a performance shaping factor [6]. PSFs can be divided into three classes: External PSFs, Internal PSFs and Stressors. In view of the flight task features and the flight deck design philosophy, the pilot's PSFs are discussed here.

(1) External PSFs

External PSFs are situational characteristics, task & equipment characteristics and job & task instructions. The situational characteristics include cockpit environment (e.g. temperature, humidity, air quality, noise, illumination, etc.), work & break hours, shift rotation & night work, availability and adequacy of equipment/system. The task & equipment characteristics include perceptual requirements, motor requirements, complexity, criticality, frequency & repetitiveness and man-machine interface factors. The job & task instructions include flight manual, procedures, oral/paper communication, alert and attention.

(2) Internal PSFs

Internal PSFs are pilot training experience, working experience & skill, sex differences and physical condition. Whereas the flight crews are well trained and qualified, the internal PSFs will not have conspicuous effect on human error probability compared with the external PSFs.

(3) Stressors

The stressor is any external or internal force that causes bodily or mental tension [6]. It appears to arise whenever there is a mismatch between the internal PSFs and the external PSFs. Stressors can be psychological, physiological, or a combination of both. The psychological stressors include task speed, workload, high risk, threats and disturb. The physiological stressors include duration of stress, fatigue, pain or discomfort, hunger or thirst, temperature extremes, radiation, oxygen insufficiency, vibration and disruption of circadian rhythm.

3. Method to Assess Flight Crew Errors

In view of the whole flight operation environment, the process to assess flight crew errors is shown in Fig 2. It is based on THERP method.

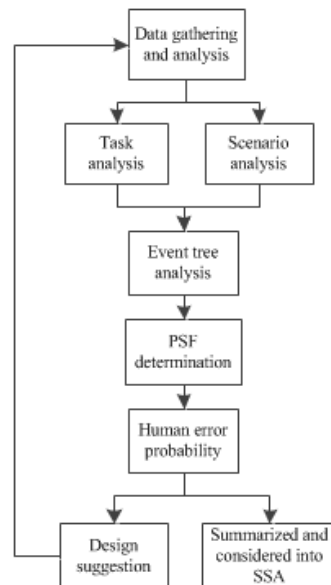


Fig. 2. Flow chart of human error assessment

There are 9 steps in this process:

(1) Data gathering and analysis

Gathering all the information related to flight crew errors, e.g. design deficiency data, accidents/incidents data and flight manual.

(2) Task analysis

In this paper, we use HTA method [7] to analyze flight task. The most remarkable points in this step are the stopping rule and the rule to select critical operations. In order to predict the flight crew errors, it should be analyzed in each sub-operation. Considering the flight task features, the goal should be decomposed to two levels.

In view of SSA objectives, it is impossible and unnecessary to calculate each identified operational task. The operational task, of which the failure condition is catastrophic, hazardous or major, needs both qualitative and quantitative assessments. Hence for the rule to select critical operations, once some operation is forbidden in flight manual or has induced flight accidents/incidents that it need to be selected in decomposition of sub-goal. The others should be selected on the discussion with the flight specialists or the test.

(3) Scenario analysis

Scenario analysis is based on the acknowledged events or the perspectives. It includes the behaviors under given conditions/context. Several components should be considered such as participant, equipment & environment, task and the abnormal condition.

(4) Event tree analysis

According to the results of task analysis, the event tree is established. The aim is to analyze human errors.

(5) PSFs determination

PSF has been discussed in section 2.2. Different scenario presents different PSFs. PSF depends on the scenario assumed.

(6) Determination of human error mode

Human error modes have been discussed in section 2.1. It will be determined based on the final task analysis.

(7) Human error probability

The human error probability lies on the specialists' judgment, the test analysis or the experience used in other correlative fields as references.

The effects due to personal differences and environment on the human performance, should be concerned. The realistic human error probability of each subtask will be corrected by PSFs:

$$BHEP = NHEP \times PSF1 \times PSF2 \times \dots (1)$$

In formula 1, NHEP is nominal human error probability which is the realistic probability without consideration of the influences from environment and personal differences. BHEP is basic human error probability which is the probability of a human error on a task. It is considered as an isolated entity and unaffected by any other task. PSF1, PSF2, ... are the values of different PSFs.

The failure probability of each subtask in the Event tree is a conditional probability. The interdependence among subtasks, which is important in risk assessment, should be considered while calculating conditional probability. Without consideration of interdependence of the events, the risk will be underestimated, and the safety level will be sequentially reduced.

Generally, the methods for assessing interdependence are as the following:

- (a) Use of the actual data.
- (b) Objective evaluation.

(c) Use of positive dependence model [5] in which dependences are classified into five types: zero dependence(ZD), low dependence(LD), moderate dependence(MD), high dependence(HD) and complete dependence(CD).

In this paper, because of the limitation of data, only the positive dependence model is applied.

(8) Human error management

The effective management should be performed specially on the failure condition which is major, hazardous or catastrophic, as well as those very high frequency occurrences. Design is an effective way to manage human error, e.g. making proper operational procedure, deploying reasonable operational task or error prevention design. Each aspect of SHEL model should be considered and carefully designed.

(9) System Safety Assessment

As required in FAR/CS part 25 and the correlative policy and memo [8,9], the results will be an evidence for the system designer to proof whether the design is acceptable or not. It can also be the input of PSSA and CMA.

4. Case Studies

In this paper, the takeoff phase of A320 is studied. The task analysis is performed under the HTA method as shown in Fig 3.

The human error modes and the consequences induced by each subtask are analyzed and summarized in Table 2.

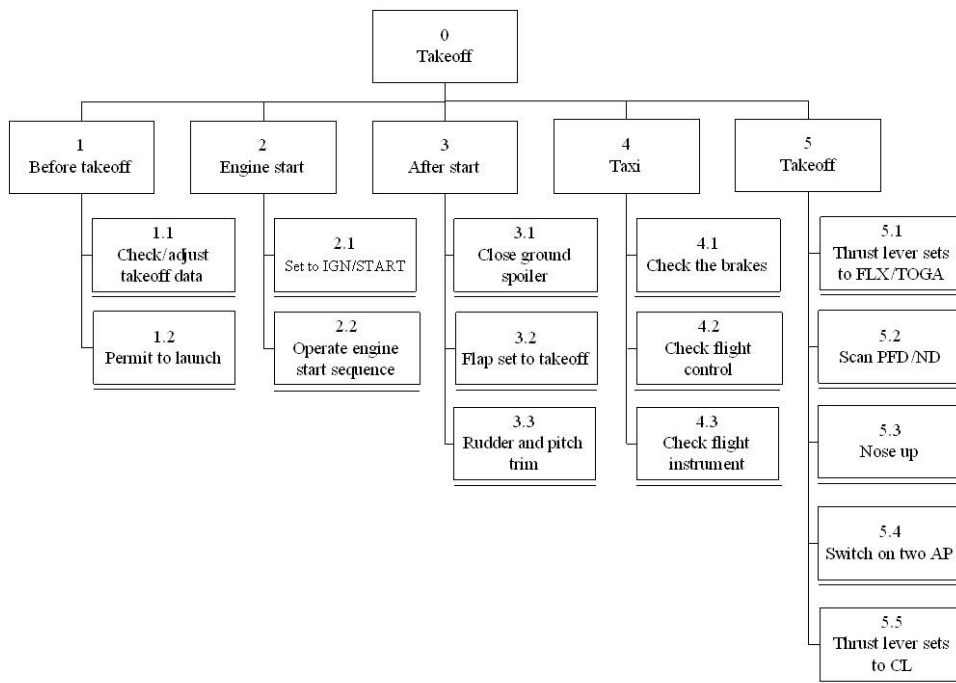


Fig. 3. Task analysis in the takeoff phase

Table 2 Human error modes and consequences in the takeoff phase

Subtask	Human error mode	Description	Consequence
Check/adjust takeoff data	Omit	The flight crew forgets to calculate takeoff speed and neither check takeoff configuration nor validate takeoff weight limitation.	The appropriate takeoff speed cannot be determined.
	Lapse	PF does not calculate takeoff speed and FLX temperature independently. Misread the number.	The calculation result cannot be verified. The calculation result is wrong.
Permit to launch	Timing error	Misunderstand that the aircraft is permitted to launch and then execute it.	Ground accident could occur.
Set to IGN/START	Timing error	Before permit to launch, task is executed.	Ground accident could occur.
Operate engine start sequence	Sequence error	The engine start sequence is operated wrong.	The engine cannot be started.
Close ground spoiler	Lapse	Ground spoiler is armed.	The acceleration is abnormal and the distance of takeoff needs to be longer.
Flat set to takeoff	Lapse	Flat position is set incorrectly.	Influence on takeoff performance.
Rudder and pitch trim	Spatial illusion	Because of the different views, it is not trimmed indeed.	The aircraft needs to be controlled manually.
Check the brakes	Omit	Forget to check the brakes	The distance of takeoff is too long.
Check flight control	Omit	Forget to check flight control	Influence on flight control.
Check flight instrument	Omit	Forget to check some flight data.	Do not understand the condition of the aircraft.
	Lapse	The parameters in the instrument are misread.	Influence on takeoff performance.
Thrust lever sets to FLX/TOGA	Lapse	The thrust lever sets to the wrong position.	The thrust is incorrect.
Scan PFD/ND	Omit	The flight data is abnormal and is not cognized by pilot.	Influence on flight performance and flight path.
	Lapse	Pilot does not cognize something wrong.	Influence on flight performance and flight path.
Nose up	Timing error	The control stick is moved too early.	It need more force to control the stick.
		The control stick is moved too late.	Tail strike
	Force error	Too much pitch angle	Tail strike
Switch on two AP	Omit	Two AP are not switched on.	Not controlled by two AP.
Thrust lever sets to CL	Timing error	Set to CL too early.	Influence on climb performance.
		Set to CL too late.	Influence on engine.

We assume that the human performance is reduced due to fatigue. Fatigue includes acute fatigue and chronic fatigue. The fatigue will be induced by shift work or flight delay, so it is an acute fatigue. An acute fatigue can be cured after a nice sleep or rest. The intension of an acute fatigue is higher than a chronic one, but it is temporary and of short duration. The acute fatigue is included in the external PSFs. We assume that PSF equals to 2. Nominal human error probability is assumed to be 0.0004 referring to HEART method [10]. Each subtask is individual, that is to say, the dependence between each subtask equals to Zero.

In this case, all of the subtasks are in the series. One task fails, the whole task fail. The event tree is shown in Fig 4.

Therefore, the failure probability of the task induced by human errors in takeoff phases can be calculated as follows:

(1) Basic human error probability

$$BHEP = NHEP \times PSFs = 0.0004 \times 2 = 0.0008$$

(2) Probability of the whole task

$$HEP = 1 - (1 - 0.0008)^{15} = 0.0113$$

Finally, we obtain that the failure probability of the whole task in takeoff phase is 0.0113.

In this case, fatigue is the major contributory factor of human errors. Furthermore, the consequence caused by it can be very severe, especially in takeoff phase. Although the fatigue cannot be directly eliminated by hardware design, it can be catabatic by other ways. For example, caffeine is a legal drug to keep people alert. Or by procedure design or training, for example, the cross checking is an effective way to resolve it.

The result calculated will be feedback to SSA. The system designer will think about whether it is acceptable or not, thus, the improvement of the current design will be addressed.

Likewise the human error modes and the consequences will be considered into PSSA and CMA.

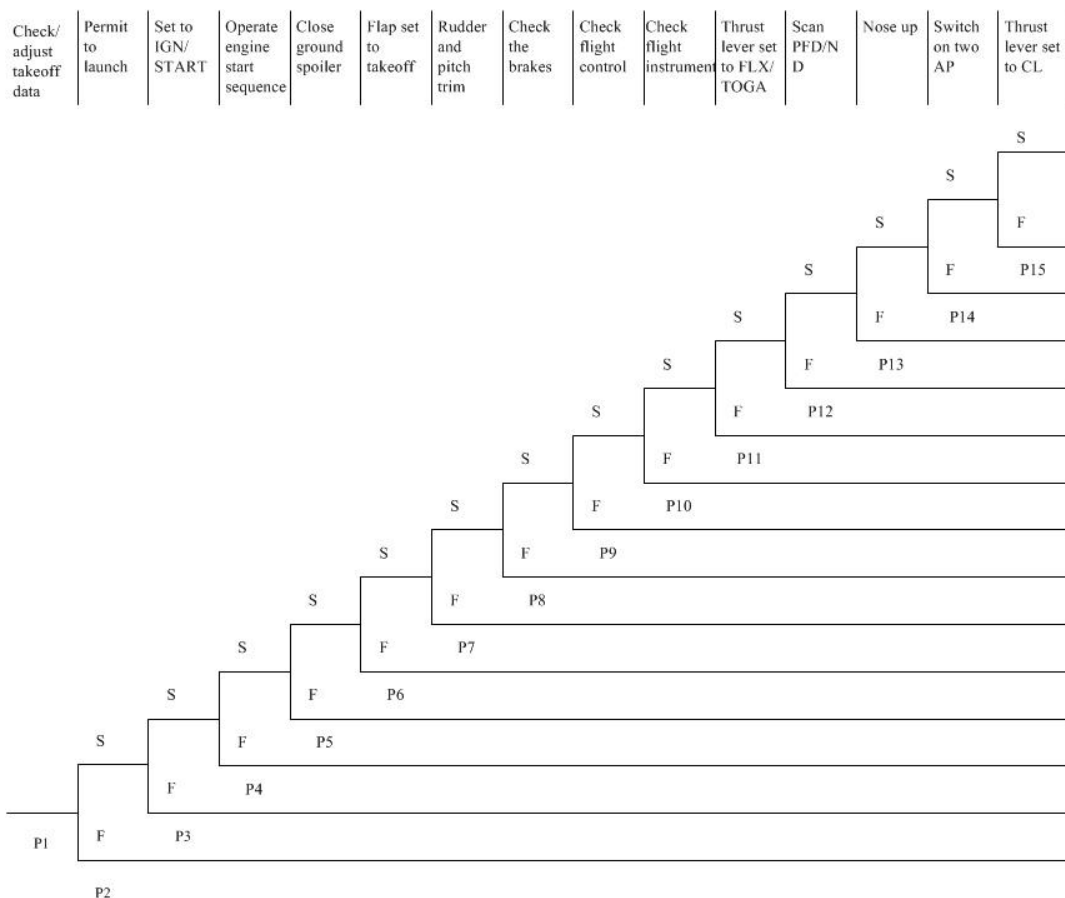


Fig. 4. Event tree in the takeoff phase

5. Conclusions

Human error identification technique is an important part of HRA. A flight crew errors analysis and classification system is established to identify the human error modes. A method to assess flight crew errors is established based on THERP. In combination with the task analysis in takeoff phase and the interviews with pilots, flight crew errors are qualitatively analyzed. According to the event tree and scenario analysis, the failure probability of takeoff task is calculated.

The results will be used into PSSA and CMA, and provide suggestions for the improvement of the system design.

There are still some issues to be addressed in flight crew errors assessment. Firstly, there may be a number of factors concerned in the task analysis. Together with the scenario analysis, the global task analysis shall also be addressed. Secondly, the interdependence among subtasks shall be more carefully determined, since it may cause the significant influence on the conditional human error probability. Finally, different scenario will lead to different conclusions. How many scenarios that need to be taken into account, is a notable problem to the system designers.

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References

- [1] Demagalski, J., Harris, D., Salmon, P., et al. Design Induced Errors on the Modern Flight Deck During Approach and Landing[C]. HCI-Aero 2002 Proceedings, 2002, p.173-178
- [2] Harris, D. Rule Fragmentation in the Airworthiness Regulations: A Human Factors Perspective. Engineering Psychology and Cognitive Ergonomics[C], Proceedings 9th International Conference, EPCE 2011, 2011, p.546-555
- [3] Nelson, W. R. Integrated Design Environment for Human Performance and Human Reliability Analysis[C]. IEEE Sixth Annual Human Factors Meeting, 1997, 8-7-8-11
- [4] Society of automotive engineers, inc. Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne System and Equipment, SAE ARP4761, 1996
- [5] Hollnagel, E. Cognitive Reliability and Error Analysis Method[D], Elsevier, London, 1998
- [6] Swain, A.D., Guttman, H.E. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications[D]. NUREG/CR-1278, Washington, DC: US Nuclear Regulatory Commission, 1983
- [7] Shepherd, A. HTA as a Framework for Task Analysis. Ergonomics[J], 1998, 41(11): 1537-1552
- [8] Federal Aviation Administration (FAA). Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks, PS-ANM111-1999-99-2, Federal Aviation Administration, Washington DC, USA, 1999
- [9] Federal Aviation Administration (FAA). Factors to Consider when Reviewing an Applicant's Proposed Human Factors Methods of Compliance for Flight Deck Certification, PS ANM100-01-03A, Federal Aviation Administration, Washington DC, USA, 2003
- [10] Williams J. C.A Data-Based Method for Assessing and Reducing Human Error to Improve Operational Performance[C]. Fourth Conference on Human Factors and Power Plants, 1988, p.436-450
- [11] Harris, D., Stanton, N.A. Aviation As A Systems : Preface to The Special Issue Of Human Factors In Aviation[J], Ergonomics, 2010, 53:145-148

- [12] Kirwan, B. The Validation of Three Human Reliability Quantification Techniques – THERP, HEART and JHEDI: Part II - Results of Validation Exercise[J]. *Applied Ergonomics*, 1997, 28: 17-25
- [13] Kirwan, B. Human Error Identification Techniques for Risk Assessment of High Risk Systems - Part 1: Review and Evaluation of Technique[J]. *Applied Ergonomics*, 1998, 29: 157-177
- [14] Kirwan, B. Human Error Identification Techniques For Risk Assessment Of High Risk Systems – Part 2: towards a framework approach[J]. *Applied Ergonomics*, 1998, 29: 299-318
- [15] Shorrock, S.T., Kirwan, B. Development and Application of A Human Error Identification Tool for Air Traffic Control[J]. *Applied Ergonomics*, 2002, 33: 319-336
- [16] Stanton, N., Harris, D., Salmon, P. M., et al. Predicting design induced pilot error using HET (Human Error Template) – A new formal human error identification method for flight decks[J]. *Journal of Aeronautical Sciences*, 2006, 110: 107-115